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Atmospheric impacts of a natural gas development within the urban context of Morgantown, West Virginia ☆

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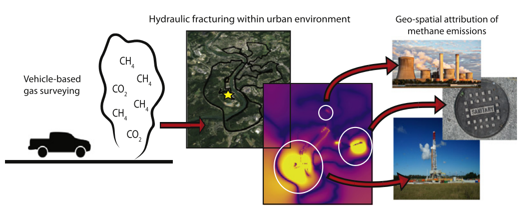
HIGHLIGHTS

- Methane emissions peaked during flow-back phase.
- Methane emissions were minimal during early drilling stages and after flow-back.
- Urban sources can mimic geochemical fingerprint of natural gas emissions.

GRAPHICAL ABSTRACT



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ABSTRACT

The Marcellus Shale Energy and Environment Laboratory (MSEEL) in West Virginia provides a unique opportunity in the field of unconventional energy research. By studying near-surface atmospheric chemistry over several phases of a hydraulic fracturing event, the project will help evaluate the impact of current practices, as well as new techniques and mitigation technologies. A total of 10 mobile surveys covering a distance of approximately 1500 km were conducted through Morgantown. Our surveying technique involved using a vehicle-mounted Los Gatos Research gas analyzer to provide geo-located measurements of methane (CH_4) and carbon dioxide (CO_2). The ratios of super-ambient concentrations of CO_2 and CH_4 were used to separate well-pad emissions from the natural background concentrations over the various stages of well-pad development, as well as for comparisons to other urban sources of CH_4. We found that regional background methane concentrations were elevated in all surveys, with a mean concentration of 2.699 ± 0.006 ppmv, which simply reflected the complexity of this riverine urban location. Emissions at the site were the greatest during the flow-back phase, with an estimated CH_4 volume output of 20.62 ± 7.07 g/s, which was significantly higher than other identified urban emitters. Our study was able to successfully identify and quantify MSEEL emissions within this complex urban environment.

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1. Introduction

Fugitive emissions are a significant concern for the oil and gas industry, as they can contribute long-lived greenhouse gases (GHG's) such as methane (CH_4) and carbon dioxide (CO_2) to the atmosphere (EPA, 2011; Pétron et al., 2012; Wang et al., 2014; Tom, 2011) . Recent advancements in the oil and gas industry have enabled companies to target low permeability reservoirs and natural gas contained therein. In the context of electricity generation, natural gas emits roughly 50 to 60% less CO_2 when compared to coal combustion (Atherton et al., 2017; Vinciguerra et al., 2015) , but this advantage can be negated if CH_4 emissions exceed 3% of the natural gas extracted over the lifetime of the well (Alvarez et al., 2012; Howarth et al., 2011; Vinciguerra et al., 2015) because CH_4 has a global warming potential 28–34 times greater than CO_2 on a 100-year horizon (Caulton et al., 2014; Change, 2013; Howarth et al., 2011; Miller et al., 2013) .

The oil and gas industry develops low permeability reservoirs using multi-stage hydraulic fracturing (or "fracking") which involves the high-volume injection of water, sand and chemicals into the target formation (Bradbury et al., 2013; Howarth et al., 2011; Jiang et al., 2011; Stephenson et al., 2011) . Past studies have recognized the need for accurate inter-stage emission estimates for fracking operations (Allen et al., 2013; Howarth et al., 2011; Jiang et al., 2011; Pekney et al., 2014; Vinciguerra et al., 2015) . This knowledge can improve current inventories, focus regulatory efforts, and empower oil and gas companies to better control their carbon footprint.

The development of an unconventional well-pad can be broadly categorized into three stages: pre-production (drilling and well pad construction, including hydraulic fracturing), flow-back and production. The flow-back phase generates the highest momentary levels of GHG emissions (Allen et al., 2013; Bradbury et al., 2013; Howarth et al., 2011; Jiang et al., 2011; Rich et al., 2014) , as hydrocarbon fluids (mostly CH_4) from the target formation are entrained or dissolved within the flow-back fluids and released at the surface. A comprehensive study by Allen et al. (2013) measured emissions from 5 well completion flow-backs in the Appalachian region, and observed emissions averaging 11.8 g/s CH_4. It is also important to note that flow-back emissions can vary significantly, and are highly dependent on whether reduced emission containment systems (RECs) are present during flow-back procedures (Balcombe et al., 2016) . Combustion emissions are most prevalent during early drilling operations, usually as a by-product of drilling equipment, diesel engines, and well-pad construction work (Jiang et al., 2011) . Methane emissions can also be present during production stages, but are typically fugitive and associated with events such as the incomplete combustion from flare stacks, well work-overs and equipment leaks (Bradbury et al., 2013; Burnham et al., 2011; Jiang et al., 2011) .

The natural gas industry in the Appalachian region has been rapidly expanding in the past decade. As a consequence of this development, the presence of well-pads in urban areas is becoming an increasingly common occurrence (McKenzie et al., 2012a) . The broader environmental impacts of shale gas development in urban areas targeting the Marcellus Shale have been studied in the past (Arthur et al., 2009; Brasier et al., 2011; Jiang et al., 2011; Vidic et al., 2013) . However, detailed analyses of atmospheric emissions from urban natural gas developments are scarce, due in part to the difficulty in assessing the multiple sources present in a complex urban environment. Urban residential and industrial, ecosystem, and abiotic factors such as diurnal cycling, changing seasons, varying wind speed and direction, and elevation can all exert controls on urban methane (SA Zimov et al., 1996; Ziska et al., 2001).

Several studies have demonstrated that vehicle-based measurements using new portable GHG analyzers can offer the precision necessary to distinguish the sources of atmospheric gases in complex environments, while maintaining the ability to cover large areas (Atherton et al., 2017; Jackson et al., 2014; Lamb et al., 1995; Phillips et al., 2013a) . Vehicle based monitoring is not uncommon in cities, for example to survey the natural gas distribution system for leaks (Jackson et al., 2014; Lamb et al., 1995; Phillips et al., 2013a) . But, the focus there is on localized impacts, and doesn't involve the partitioning of regional anomalies created by specific types of development within the urban environment, and/or integrating the temporal nature of those anomalies.

Our study involved a multi-gas (CO_2, CH_4) mobile surveying technique used to analyze atmospheric gases in proximity to the oil and gas development in the city of Morgantown, West Virginia. In the study, we analyze atmospheric gas concentrations through several surveys spanning multiple stages of development from early drilling to production. Our study seeks to analyze the frequency and severity of CH_4 emissions throughout the many stages of development of an urban natural gas well pad, and how they compare to other sources within the broader urban context of Morgantown. We believe that CH_4 emissions will be negligible during the early drilling stages, with emissions peaking during flow-back and lessening (albeit still present) after the well pad enters production stages. In addition, we believe that urban sources will be frequently detected throughout surveys but emission severities will be low when compared to the MSEEL well pad.

2. Methods

2.1. Site description

Our study site is the Marcellus Shale Energy and Environment Laboratory (MSEEL) in Morgantown, West Virginia (Fig. 1). The Marcellus Shale is one of the more recent shale gas formations to be developed in the U.S., with the first economically productive wells drilled in Pennsylvania as recently as 2005 (US, 2009) . The Marcellus Shale is also one of the largest shale plays in the U.S., covering an area of roughly 95,000 square miles (Arthur et al., 2009; Brasier et al., 2011; US, 2009; Kargbo et al., 2010). Development of the Marcellus Shale has been focused in Pennsylvania and West Virginia, with thousands of wells drilled since 2005 (US, 2009) . The MSEEL site is located on the southern edge of Morgantown, a riverine urban area characterized by varying topography and a humid temperate climate (Fig. 1).

The study site consists of a single well pad supporting two active natural gas wells identified as MIP-5H and MIP-3H, each with two corresponding horizontal shafts. A science well is also present within km of the well pad, which was used to gather sub-surface data that is not presented in this study (Fig. 1). MSEEL wells were initially inactive, and were developed over the course of this longitudinal study. There were also two pre-existing production wells on the well pad (MIP-4H and MIP-6H), which were actively producing throughout the course of the study (Fig. 1).

An urban location such as Morgantown typically has a multitude of methane sources. In addition to wastewater treatment facilities, minor landfills and a coal-fired power plant, the Monongahela River running through Morgantown may act as a methane source from biological respiration (Butman and Raymond, 2011) and/or CH_4 ebullition (Bastviken et al., 2011) . A possible industrial source of methane emissions in the region include the Morgantown Energy Facility, which is a coal-fired power plant located in the northern section of Morgantown. Coal-fired power plants have been associated with significant methane emissions in previous studies (EPA, 2011; Tom, 2011) , therefore this location was flagged as a high potential location for emissions. Sewer (or storm) drains have also been recognized as methane sources (Guisasola et al., 2008, 2009) . Several studies have identified sewer systems as providing the ideal anaerobic conditions for the production of gases such as CH_4 and hydrogen sulfide (H_2S) (Guisasola et al., 2008; Kim et al., 2009; Rosso and Stenstrom, 2008), with rising sewer water levels exacerbating